IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of: TRACEY A. CAVATO, TIMOTHY R. COOMBE, SCOTT C. JOHNSON	§	Confirmation No.: **5924**
	§	Group Art Unit: **1638**
Serial No.: **10/523,290**	§	Examiner: **Anne R. Kubelik**
Filed: **October 19, 2005**	§	Atty. Dkt. No.: **11899.0262.PCUS00**
For: **Corn Event PV-ZMIR13 (MON863) Plants and Compositions and Methods for Detection Thereof**	§	

Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

REPLY TO REQUEST FOR INFORMATION UNDER 37 CFR §1.105

Sir:

In response to the Request for Information under 37 CFR §1.105 dated February 19, 2009, having an extended period for response expiring July 19, 2009, Applicants submit the following information as requested in the form of a declaration under 37 CFR §1.132. A petition for a three-month extension of time is filed concurrently.

<u>**Declaration of John R. Anderson, Jr., Ph.D., Under 37 CFR §1.132**</u>

I, John R. Andersen, declare the following:

1. I earned a doctorate degree in Agronomy and Plant Physiology from the University of Illinois Urbana-Champaign in 1978. I have been employed by Monsanto Company since January 1, 1998. Monsanto Company is the parent company wholly owning Monsanto Technology LLC, the assignee of the above captioned patent application. I have worked in the Technology Development function during my eleven years of employment with Monsanto Company and have managed a diverse portfolio of research projects examining the economic and environmental impacts of crop biotechnologies. I have held positions entitled Market Development Representative, and Technical Development Manager and Lead, Technical Resources Teams. My present position is entitled Director, Technology Development, and carries with it the responsibility for managing: (a) technical projects that describe and model the performance and risk reducing attributes of crop biotechnologies, (b) diverse, technical activities involving academic scientists, independent crop consultants and professional farm managers, and (c) technical issues involving the conservation community. As a result of these responsibilities, I maintain a network of the nation's leading economists and often retain them to analyze and mathematically estimate the biological and economic performance of Monsanto technologies and products. For example, in 2007 the Federal Crop Insurance Corporation Board, supported by the United States Department of Agriculture (USDA) Risk Management Agency, approved the Biotech Yield Endorsement, the first, approved crop insurance product based upon a technology. I was the technical lead for the team that created the Biotech Yield Endorsement and worked with several economists to complete the actual work for that innovation that involved calculation of production risk reductions associated with three biotech crop traits combined into a single

corn hybrid. MON863 was one of those three traits. Starting in 2001 and working with MON863 and other biotech crop traits, I contracted and collaborated with academic economists to develop the concept that much of the farm gate value of crop biotech traits is manifested in non-pecuniary benefits, e.g. simplicity, convenience and peace of mind. That initial modeling and survey work was largely theoretical and it resulted in manuscript subsequently written by Drs. Julian Alton, Michele Marra, Jeffrey Hyde and Paul Mitchell and later published in 2002, further discussed below.

2. I have read, I understand, and I am familiar with the issues related to the Mitchell paper (May 2002, *Yield Benefit of Corn Event Mon 863*, In: Faculty Paper Series, Department of Agricultural Economics, Texas A&M University) with respect to the Request for Information under 37 CFR §1.105 dated February 19, 2009 in the above captioned application. I also understand that the effective filing date for the above captioned application corresponds to the date the provisional application, to which the above captioned application claims priority, was filed, and that the provisional application was filed on July 29, 2002.

3. As a result of my employment with Monsanto Company and the nexus that my employment positions have had with respect to the development and commercialization of the referenced transgenic event MON863, it is my opinion that there was no sale or other public distribution of the claimed plant/seed anywhere in the United States prior to the effective filing date of the above captioned application based on the following reasoning.

4. Monsanto Company contracted with the University of California at Davis *via* its membership in the National Science Foundation (NSF) Center for Integrated Pest Management (CIPM) at North Carolina State University in late 2001 under confidentiality to conduct an economic study on the potential benefits of Monsanto's rootworm technology in the MON863 event. Dr. Julian Alston of the University of California at Davis was the lead investigator of that study, who was working with Dr. Michele Marra of North Carolina State University. I quickly organized the study because it was to be included in a regulatory submission to the Environmental Protection Agency (EPA) describing benefits of the technology.

5. Since MON863 event yield data was limited but root damage rating data for the MON863 event was more readily available, Monsanto Company contracted with Dr. Paul Mitchell of Texas A&M University to work on the above economic study. This work-for-hire included standard confidentiality provisions. Dr. Mitchell predicted yield results from the root damage rating data supplied to him by Monsanto Company. No MON863 seed, plants or other biological materials were provided to Dr. Mitchell. Those yield predictions were used by Drs. Alston and Marra to estimate economic impacts including pecuniary and non-pecuniary benefits of the technology. Dr. Jeffrey Hyde of Pennsylvania State University was contracted by Monsanto Company to create enterprise budgets for Drs. Alston and Marra that illustrated the economic value of the technology. Attached is a copy of a 2002 AgBioForum publication of that study. Dr. Mitchell's principal contribution to that manuscript is found in Table 4 in the form of "yield increase factors".

6. Dr. Mitchell did not receive any seed or other biological materials related to MON863 from Monsanto Company, but instead was invited to evaluate root rating data supplied by Monsanto Company and relate the data to yield mathematically. Dr. Mitchell's work with the MON863 technology was based upon predictive models and merely theoretical.

7. Therefore, based on my experience with this transgenic event and its development, and the facts that I declare herein above, it is my opinion that no sale or offer for sale for the MON863 transgenic corn event was made prior to the effective date of the instant application, and that there was no public use of this material prior to the effective date of the instant application. That is, corn event MON863 was not publically available in any form, commercially or otherwise, prior to the effective filing date of the instant application.

8. I hereby declare that all statements made herein are of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Date: July 17, 2009

AgBioForum, 5(3): 71-84. ©2002 AgBioForum.

An Ex Ante Analysis of the Benefits from the Adoption of Corn Rootworm Resistant Transgenic Corn Technology

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If a new corn rootworm resistant transgenic corn technology had been adopted on all of the United States acres treated for corn rootworm in the year 2000, the total benefits in that year alone would have been $460 million: $171 million to the technology developer and seed companies, $231 million to farmers from yield gains, and a further $58 million to farmers as nonpecuniary benefits associated with reduced use of insecticides. Our nationwide survey of corn producers suggests that initial adoption might be as low as 30%, implying first-year benefits of about $138 million.

Key words: biotechnology, corn rootworm, economic benefits, nonpecuniary benefits.

Introduction

Transgenic technologies are changing the face of agricultural production. The innovation process that began to take commercial effect less than ten years ago already has had major impacts, and the significance and value of those past impacts has been evaluated in a rapidly growing number of economic evaluation studies (e.g., see Marra, Pardey, and Alston, 2002 for a review of the work on farm-level impacts). The past evaluation studies have included both *ex ante* and *ex post* evaluations of both farm-level and aggregative impacts. In all such work, issues arise about the methods and data used and their implications for the analysis. In this paper we report the results of an *ex ante* analysis of an important new transgenic corn technology, the first introduction of which is Monsanto's Yieldgard® Rootworm. It is described in our survey work as "CRW-resistant transgenic corn"—a generic transgenic corn developed to be resistant to the corn rootworm, planted with a seed treatment to control additional corn insect pests.

The purpose of this study was to estimate the likely economic impacts in the United States (US) of the commercial adoption of such technology. The study involved evaluating the farm-level economic impacts of the adoption of CRW-resistant corn varieties and translating those farm-level impacts into an estimate of the economy-wide impacts. In conducting this analysis we used information from an extensive data base on the actual incidence of the problems across agroecological environments, experimental data on the consequences of the alternative treatments for corn rootworm (various pesticides and CRW-resistant transgenic corn technology) under different levels of corn rootworm infestation, and a computer-assisted telephone survey of 601 US corn farmers.

The scope of a study of this type could be very broad. Adoption responses are central to the analysis of new technologies. These responses are driven primarily by relative profitability, which, in the case of seed technologies such as CRW-resistant transgenic corn, depends on the price of the new seed, its performance, and on the availability, nature, and relative price of close substitutes (including other CRW-resistant corn technologies or conventional CRW control technologies). The availability and relative price of the various alternatives not only determine adoption response, but are also critical determinants of the benefits from any particular technological package at the level of both the individual farm and the nation. To make the problem manageable, we adopted a counterfactual approach, in which we compared hypothetical (counterfactual) alternatives against the actual past outcomes, under a set of assumptions that would imply a specific pattern of adoption. Specifically, we set out to estimate what would have been the impacts in a specific recent past year—i.e., 2000—if CRW-resistant transgenic corn technology had been available, was priced such that the variable cost per acre would be the same as for a representative conventional (nontransgenic) CRW control technology, and was the only transgenic CRW control technology available.

The remainder of this paper is structured as follows. In the next section, we begin with a brief discussion of the nature of the economic problem caused by corn rootworm, including relevant information about the biology of the pest, its prevalence, the extent of the economic damage it causes (including both control costs and crop losses), and its implications for production practices (including rotations and the use of insecticides, and some of the burdens these impose on farmers and their neighbors). Key simplifying assumptions used in the

analysis are set forth in the third section. The fourth section lays out an approach to understanding and quantifying the economic determinants of the likely future patterns of adoption of the new transgenic CRW technology, and for translating those patterns into estimates of farm-level and national benefits. The fifth section presents the actual methodology used in this study and the quantitative results on farm-level benefits. Along with best-bet estimates, we provide some simple sensitivity analysis to show how the benefits from adoption depend on key variables in the analysis. These measures of benefits include only the pecuniary benefits associated with improvements in farm productivity. They do not include some nonpecuniary benefits perceived by farmers, associated with the use of nonchemical technologies. Measures of these nonpecuniary benefits, based on a survey of corn growers, are presented in the sixth section. The final section summarizes results and concludes the article.

Nature and Economic Importance of Corn Rootworm

Corn rootworm (*Diabrotica* spp.) causes extensive economic damage to corn in the United States. Populations of the western corn rootworm (*D. virgifera virgifera* Le Conte) and the northern corn rootworm (*D. barberi* Smith and Lawrence) together are estimated to result in annual yield losses and control costs that exceed $1 billion (Metcalf, 1986). The larvae hatch in the spring and feed on corn roots for several weeks. The damage to the roots can result in stunted growth of the corn plant, lodging, and eventual yield losses. Adults emerge from the soil in the summer and female adult corn rootworms lay their eggs to overwinter in the soil. Dense populations of feeding adults can cause some yield loss but most of the damage is caused by the root feeding of the larval stages (Wright, Meinke, & Jarvi, 1999).

In general, corn rootworms cannot complete their life cycle without the food supplied by corn plants. Therefore, until recently they caused damage almost exclusively in fields where corn is grown at least two years in a row. A crop rotation with one year of corn has been an effective control strategy. Lately, however, two variants of corn rootworm have developed. The soybean variant (SBV) of the western corn rootworm has adapted its egg-laying behavior to lay eggs in crops other than corn (Levine & Oloumi-Sadeghi, 1996). So, in areas where corn/soybean rotations are common, eggs laid in soybean fields will hatch in corn fields in the following spring. It evolved in eastern Illinois and has since spread into Indiana, Michigan, and Ohio (Onstad et al., 1999). The extended diapause variant (EDV) of the northern corn rootworm has adapted to two-year corn rotations as well (Krysan, Jackson, & Lew, 1984). Although most corn rootworm eggs hatch in the following spring, for the EDV, some of the eggs hatch after two winters, and thus the larval stages are able to feed on corn roots even in rotated corn. The EDV is most prevalent in eastern South Dakota, northeastern Nebraska, northwestern Iowa, and southeastern Minnesota.

We identified a total of 11 distinct corn production regions (or subregions) in the United States, which we treat as separate agroecologies for the purposes of this analysis. The regions are roughly equivalent to the nine Farm Resource Regions as recently defined by the Economic Research Service (ERS) of the US Department of Agriculture (Heartland, Northern Crescent, Northern Great Plains, Prairie Gateway, Eastern Uplands, Southern Seaboard, Fruitful Rim, Basin and Range, and Mississippi Portal) plus two additional subregions within the Heartland where the two corn rootworm variants—the extended diapause variant (the EDV region) and the soybean variant (the SBV region)—are currently found. Table 1 presents an overview of corn production in the 11 regions as defined in this study. Within all of the regions corn is grown either continuously or as an element of a crop rotation plan. In many regions, corn rootworm is a significant problem only in continuous corn. In the Heartland region in particular, however, corn rootworm damage can be a significant problem both in first-year corn (corn grown where a different crop was grown in the previous year) and in continuous corn (corn grown where corn was grown in the previous year). These observations are reflected in the figures for the percentages of continuous and first-year corn acreage treated for corn rootworm (Table 1), and the treated acres of continuous and first-year corn (Table 2). Multiplying the total acreage by the percentage treated for corn rootworm in Table 1 yields the number of acres treated. Note that in the figures for treated acres in Table 2, some acres are counted more than once, reflecting the fact that some acres were treated more than once.

Control methods available currently to deal with the corn rootworm problem include (a) crop rotation (in all but the EDV and SBV regions), (b) soil-applied insecticides to control corn rootworm larvae, and (c) insecticide sprays to control corn rootworm adult beetles. The opportunity cost of rotation is assumed to be positive in many areas, given the large acreage of continuous corn each year. Table 2 presents an overview of conventional

Table 1. Corn acreages and shares treated for CRW in 2000.

Region	Total Area Planted to Corn (acres)	Share Treated for CRW (%)	Total Area of Continuous Corn (acres)	Share Treated for CRW (%)	Total Area in First-Year Corn (acres)	Share Treated for CRW (%)
Mississippi Portal	1,347,885	1.0	502,916	0.0	844,969	1.5
Southern Seaboard	2,136,491	7.7	706,933	8.3	1,429,558	7.3
Fruitful Rim	882,273	50.5	432,626	52.0	449,646	49.1
Eastern Uplands	1,705,355	11.6	733,404	18.4	971,951	6.5
Northern Crescent	11,288,731	14.7	4,536,048	25.6	6,752,683	7.5
Heartland, Remaining	34,516,415	13.8	6,601,637	44.5	27,914,778	6.6
Heartland, EDV	2,788,455	5.2	265,913	12.7	2,522,542	4.4
Heartland, SBV	8,951,127	33.0	936,815	47.6	8,014,312	31.3
Northern Great Plains	4,867,966	8.7	1,442,112	26.4	3,425,855	1.3
Prairie Gateway	9,931,175	29.7	5,506,741	45.5	4,424,434	10.1
Basin and Range	211,827	33.7	112,420	55.8	99,407	8.6
Total	79,579,030	17.3	22,268,847	35.7	57,310,183	10.2

Note: From "Corn insecticide product use," Doane's Market Research (2001). Data supplied by Monsanto Company, 2001.

Table 2. Treated acres, expenditure on CRW insecticides, and average cost per acre in 2000.

Region	Total Acres Treated for CRW	Total Expenditure on CRW Insecticides ($)	Continuous Corn Acres Treated for CRW	Expenditure on CRW Insecticides for Continuous Corn ($)	First-Year Corn Acres Treated for CRW	Expenditure on CRW Insecticides First-Year Corn ($)	Average Cost of Insecticide ($ per acre)
Mississippi Portal	13,115	117,283	36	361	13,079	116,922	8.94
Southern Seaboard	163,442	1,879,948	58,497	626,588	104,945	1,253,360	11.50
Fruitful Rim: Target	445,505	5,337,143	224,830	2,758,341	220,675	2,578,802	11.98
Eastern Uplands	198,413	2,247,484	135,204	1,572,652	63,208	674,833	11.33
Northern Crescent	1,680,410	20,992,361	1,159,901	14,265,651	520,509	6,726,710	12.63
Heartland, Remaining	4,820,048	57,537,615	2,984,335	36,527,083	1,835,713	21,010,532	12.07
Heartland, EDV	145,594	1,819,104	33,640	449,777	111,954	1,369,327	12.49
Heartland, SBV	2,992,309	39,935,790	445,725	6,634,121	2,546,584	33,301,669	13.52
Northern Great Plains	532,094	5,355,880	486,724	4,983,995	45,369	371,885	12.59
Prairie Gateway	3,134,778	35,695,939	2,679,506	30,482,413	455,272	5,213,527	12.09
Basin and Range	71,282	590,972	62,719	509,743	8,563	81,229	8.29
Total	14,196,990	171,509,520	8,271,117	98,810,724	5,925,871	72,698,796	12.43

Note: From "Corn insecticide product use," Doane's Market Research (2001). Data supplied by Monsanto Company, 2001.

corn rootworm insecticide use by region in crop year 2000. The cost of soil-applied insecticides averaged about $12.43 per acre in material and application costs across the United States, but varied slightly among regions. Spraying for adult beetles is not as prevalent as soil-applied larval control (United States Department of Agriculture [USDA] National Agricultural Statistics Service, 2001). Total expenditure for corn rootworm-targeted insecticides topped $171 million in the 2000 crop year (Doane's Market Research, 2001).

Key Assumptions

As noted above, we assume that the seed price premium is set so that the variable cost per acre for the new technology equals that of the next-best alternative technology. We also assume there is no price premium or discount for the transgenic over conventional corn and that the transgenic corn yields at least as well as the conventional alternative. These two assumptions combined mean that CRW-resistant transgenic corn would have been at least as profitable per acre as the conventional

alternative. Some other factors, both pecuniary and nonpecuniary in nature, also affect the grower's decision to adopt the technology. The CRW-resistant transgenic corn technology is expected to provide a yield gain relative to conventional control, because its effectiveness does not depend on timing, weather, calibration of application equipment, or soil condition. This yield gain is estimated to range between zero and seven percent, depending on the insect pressure (Mitchell, 2002). In addition, the CRW-resistant transgenic corn technology will be safer and more convenient for operators and farm workers to handle, relative to conventional chemical treatments, and it also may yield some savings in planting time. Without the insecticide application equipment attached to the planter, larger seed hoppers can be installed, saving refilling time, and farmers may also save time spent on calibration and safety precautions. Some debate about this point exists, but farmers in our survey indicated they would be willing to pay a small amount for such savings in time and related variable costs.

Along with the other features of the technology, our pricing assumptions imply that profit-maximizing producers would have adopted CRW-resistant transgenic corn on all of the acres that were treated for corn rootworm in that year. They also imply that the benefits from any resulting yield gains (and other on-farm benefits) would have been captured entirely by farmers. The actual distribution of the benefits from this new technology among farmers, consumers of corn, and suppliers of CRW control technologies (including seed, agricultural chemical, and biotechnology companies) will depend on the nature of competition and the underlying market supply and demand conditions, which will govern the pricing and adoption of the technological alternatives. The main implication of the pricing of the technology is for the distribution of the benefits rather than for the total benefits; the pricing assumption we have adopted is both plausible and useful for obtaining a measure of farmer benefits that is a reasonable proxy for total benefits. Making assumptions about the pricing structure is unavoidable. Our particular assumptions allowed us to take greatest advantage of our detailed data on the spatial incidence of corn rootworm problems and on the adoption of alternative pesticide treatments across different agroecological environments.

Another complicating factor is insect resistance management (IRM). Because any requirements for an IRM program (such as refuge requirements) had not been defined at the time when this analysis was done, we did not allow for the implementation of an IRM program. An IRM program would involve both direct costs and indirect costs and thus would reduce the net benefits in any year. On the other hand, the purpose of any IRM program is to preserve the benefits from the new technology over a longer time period. An effective IRM program imposes costs in the short run in order to generate benefits in the longer run that are worth more than the short-run costs. If we were to consider the short-run costs, we ought also to take into account the long-run benefits, and to do this would require a full dynamic analysis of the impacts of the technology over time, factoring in the role of resistance. In the analysis below we look at the impacts of adoption of the technology in one year in a static analysis, without any consideration of the impacts over time of either increasing pest resistance or of IRM programs that might be introduced to reduce the losses resulting from resistance buildup. Until IRM plan elements are delineated, it is difficult to estimate the financial impact of IRM on growers in the static analysis. Even with knowledge of the plan elements, the full dynamic analysis would remain difficult. Onstad, Guse, Spencer, Levine, and Gray (2001), however, evaluate the effect of several biological factors on the effectiveness of refuge-based IRM for delaying the development of resistance by western CRW to transgenic corn, but do not include economics in their analysis. (Recent articles that have examined elements of the economics of refuge requirements for transgenic crops include Hurley, Babcock, and Hellmich, 2001; Hurley, Secchi, Babcock, and Hellmich, 2002; Laxminarayan and Simpson, 2002; Marra, Hubbell, and Carlson, 2001; Livingston, Carlson, and Fackler, 2000; and Mitchell, Hurley, Babcock, and Hellmich, 2002.)

Our analysis also does not allow for responses by suppliers of competing technologies. A profitable innovation provides impetus for both the current supplier and other companies to continue the development of competing technologies. Several players currently involved in this industry are devoting resources toward developing improved transgenic technologies in corn and in many other crops. Progress is sure to continue at a rapid pace. At the same time, companies selling conventional control products will respond to their loss of market share by lowering their products' prices or offering nonprice incentives. We observed this response with the previous transgenic introductions. These competitive responses will benefit all corn growers and other farmers as well (in some instances where products are labeled for other crops). It is difficult to predict, given these market forces, precisely how the total benefits

from the CRW-resistant transgenic corn technology will change over time.

Evaluation Concepts

A key element in the evaluation of the benefits from the adoption of a particular varietal technology, such as the CRW-resistant varieties of corn, is to estimate the adoption pattern—the numbers of acres (or percentages of total corn acres) annually planted to CRW-resistant transgenic corn for each of a range of different agroecologies.

In each relevant agroecology, the projected adoption paths can be defined as a function of estimates of the expected agroecology-specific yields and costs (and hence profitability) of growing CRW-resistant transgenic corn relative to the next-best alternative corn variety. We assume that all of the farmers in agroecology i will adopt CRW-resistant transgenic corn in year t if it is expected to be more profitable than the next-best alternative technology (with suitable allowance for a risk premium and for other differences including nonpecuniary aspects), which includes the option of not applying any treatment for CRW control. Algebraically, we can represent this behavior as:

$$a_{it} = \begin{Bmatrix} 1 \text{ if } \pi_{it} \geq c_{it} \\ 0 \text{ if } \pi_{it} < c_{it} \end{Bmatrix} \qquad (1)$$

where $\pi_{it} = (1-\rho_{it})(P_{it}\Delta Y_{it} - Y_{it}\Delta P_{it} - \Delta VC_t - \Delta S_{it})$ and, in agroecology i in year t,

- a_{it} is a dichotomous indicator variable that is equal to 1 if farmers in agroecology i adopt CRW-resistant transgenic corn in year t;
- c_{it} is the fixed cost per acre associated with CRW-resistant transgenic corn technology, which could entail fixed benefits from enhancements to farmer and farm worker safety associated with the use of the technology, as well as costs of risk or information costs associated with learning about the new technology;
- π_{it} is the total difference in variable profit in dollars per acre between CRW-resistant transgenic corn technology and the next-best alternative corn technology;
- ρ_{it} is the fraction of CRW-resistant transgenic corn acreage that must be planted to the next-best alternative (i.e., nontransgenic corn or other crops) to provide a refuge for nonresistant corn rootworm;
- P_{it} is the price per bushel of corn in year t, and ΔP_{it} is the price discount per bushel for corn grown using CRW-resistant transgenic corn technology, compared with conventional (nontransgenic) corn;
- Y_{it} is the average yield and ΔY_{it} is the difference in yield in bushels per acre between CRW-resistant transgenic corn technology and the next-best alternative corn technology;
- ΔVC_{it} is the difference in variable cost of production (in dollars per acre) between CRW-resistant transgenic corn technology and the next-best alternative corn technology;
- ΔS_{it} is the difference in seed price per acre between CRW-resistant transgenic corn technology and the next-best alternative.

Total benefits are given by combining information on the per acre benefits from adoption and the implied number of acres on which adoption is profitable. The area planted to CRW-resistant transgenic corn in agroecology i in year t, A_{it}, is equal to the value of the indicator variable (i.e., a_{it} = 1 or 0) multiplied by the total relevant corn acreage in agroecology i in year t, TA_{it} (corn acreage that was or would be treated for CRW). Thus, $A_{it} = TA_{it}$ if $a_{it} = 1$, and $A_{it} = 0$ if $a_{it} = 0$. The aggregate farmer benefit within agroecology i (FB_{it}) is equal to the benefit from adoption times the total area of adoption:

$$FB_{it} = \pi_{it}A_{it} = \pi_{it}a_{it}(\cdot)TA_{it} \qquad (2)$$

And, summing these benefits across all agroecologies in the nation, we can obtain a measure of the national aggregate farmer benefit from adoption in year t (FB_t):

$$FB_t = \sum_{i=1}^{I} FB_{it} = \sum_{i=1}^{I} \pi_{it}a_{it}(\cdot)TA_{it} \qquad (3)$$

The only missing element for measuring the full net economic impact is a measure of the profits of seed companies and technology suppliers, given the pricing strategy that drove the assumed pattern of adoption. The gross nonfarmer benefit ($GNFB_t$) can be estimated as the seed price premium per acre, ΔS_{it}, multiplied by the number of relevant acres and added up across agroecologies. This is a gross rather than net benefit to the extent that in addition to the costs of license fees and royalties paid by seed companies (a transfer), it might have to cover additional marketing costs that may be incurred in

developing and marketing the new seed relative to the benchmark alternative.

$$GNFB_t = \sum_{i=1}^{I} \Delta S_{it} A_{it} = \sum_{i=1}^{I} \Delta S_{it} a_{it}(\cdot) TA_{it} \quad (4)$$

Summing the farmer and nonfarmer benefits provides a measure of the total, national benefits from the adoption of the technology ($TNB_t = FB_t + GNFB_t$), the elements of which have been derived under an assumption that there are no substantial effects on the total quantity of corn produced and thus on the price of corn. If the adoption of CRW-resistant transgenic corn technology led to an increase in the total quantity of corn, and this caused a significant reduction in price of corn, there would be effects on the welfare of corn consumers (positive) as well as corn growers (negative effects on adopters and nonadopters alike, if we assume no segregation costs and no price discounts for transgenic varieties). These distributional effects would probably not mean a significant change in the overall national impact, but the distributional story might be of interest nevertheless.

This measure does not account for any impacts on the suppliers of agricultural chemicals and others whose business may be reduced as a consequence of farmers shifting to the new technology. If the industries in question could be regarded as competitive and only earning "normal" economic profits, then there would not be any net welfare impacts to consider. On the other hand, if the affected firms had been earning more than normal economic profit (such as they would if they were exercising some market power in a patented technology), then they would experience net economic losses as a result of farmers adopting the new technology, which ought to be considered in the estimate of net national benefits. Moschini, Lapan, and Sobolevsky (2002) present a model of this kind of situation. We do not have access to any information to begin to estimate such impacts.

As noted in the introduction, we adopted a strategy here of using data for a particular past year (2000) to evaluate what would have been the benefits if CRW-resistant transgenic corn technology had been commercially available in that year and was priced such that it would have been fully adopted by those farmers who treated their corn crop for CRW. Having made these assumptions, the adoption outcome was clearly defined: $a_{it} = 1$ for every acre in every agroecology that was treated for CRW in year t, and hence $A_{it} = TA_{it}$ (i.e., it is assumed that every acre treated for CRW would have adopted the new technology). This measure leaves out those acres that were not treated using conventional CRW-control technology (because it was not profitable to do so) but would be treated using the new technology (because it is more profitable than the conventional technology). On the other hand it includes some conventionally treated acres on which the transgenic alternative might not be adopted under any circumstances.

To implement this approach and estimate the benefits from having the CRW-resistant transgenic corn technology available for adoption (and adopted) in 2000, as described above we assumed that the new technology would be priced such that the variable costs of pest control per acre, including the seed premium in the case of CRW-resistant transgenic corn technology, would be equal between the new technology and a benchmark technology. That is, for the analysis, the premium for the transgenic seed was set equal to the additional variable costs per acre associated with insect control for the conventional technology (i.e., material and application costs). In addition, we assumed that there would not be any premium or discount for transgenic corn ($\Delta P_{it} = 0$) and that the fixed cost of adoption was negligible ($c_{it} = 0$), and we assume away refuge requirements (i.e., $\rho_{it} = 0$ for all i and t).

Measurement of Benefits

As described above, we identified a total of 11 distinct corn production regions, which we would treat as different agroecologies for the purposes of this analysis. We used a partial budgeting approach to estimate the per-acre net benefits of CRW-resistant transgenic corn, relative to soil insecticide control for CRW, on a representative acre for each agroecological region; we then scaled these per-acre benefits by the relevant number of acres in each region to obtain an estimate of total regional benefits. Yields, harvest costs, and (possibly) control costs were assumed to be affected by the technology choice. Yields may differ because the CRW-resistant transgenic corn technology is more effective than chemical applications in controlling CRW. Harvest costs ($0.375 per bushel) are a direct function of yields (harvest cost based on enterprise budgets from several universities—e.g., Duffy and Smith, 2002). Finally, the seed price premium is included, because it may differ from the regional average chemical control cost.

Variation in the benefit per acre across regions is determined primarily by variation in the yield gain from using the new CRW-control technology relative to the conventional (nontransgenic) alternative. In turn, this

depends on the yield potential of the crop in that region in conjunction with weather conditions and pest pressure (which in turn depends on weather, past cropping patterns within the same field, and the extent of infestations in neighboring fields). An advantage of conducting a counterfactual analysis is that we can use observations of corn production in the field under different treatments—conventional pest-management strategies and CRW-resistant transgenic corn technology—which reflect the actual situation in terms of yield potential, pest pressure, weather conditions, and so on. However, data are not available directly on the untreated (base) yields for the different agroecologies, and data are available only for root damage assessments, rather than corn yield, associated with the different treatments. We estimated the untreated corn yield and corn yield gain associated with the different degrees of root damage and the different treatments by combining actual region-specific average yield data for 2000 with information from Mitchell, Gray, and Steffey (in press), who have estimated the relationship between corn yields and root damage ratings.

A partial budget was developed for each of the 11 regions to calculate the net benefits from CRW control: soil insecticide application relative to no control, CRW-resistant transgenic corn relative to no control, and CRW-resistant transgenic corn relative to soil insecticide application. For each analysis, values were specified for a base (untreated) yield and price (USDA ERS, 2002). To calculate the yield, given CRW control, the base yield was adjusted upward by the average yield increase, based on estimates from Mitchell, Gray, and Steffey (in press) of the "average yield saved," associated with each type of control (CRW-resistant transgenic corn or chemical treatment). The (net) farmer benefit (FB_{A-B}) from control using control strategy A relative to an alternative control strategy B could then be calculated as follows:

$$FB_{A-B} = (P-H)(Y_A - Y_B) - (CC_A - CC_B) \quad (5)$$

where A indicates the control treatment of interest (using insecticide or CRW-resistant transgenic corn), B indicates the comparison treatment (applying insecticide or not applying any treatment), P is the corn price (taken from USDA ERS, 2002, and which varies among regions), Y is yield, H is harvest cost, and CC is control cost (Doane's Market Research, 2001), which is zero in untreated corn. (Alston, Hyde, and Marra, 2002, provide more details, including separate tables for each region.)

The net benefits of CRW-resistant transgenic corn relative to soil insecticide applications were found by setting each yield increase (for soil insecticide application and for CRW-resistant transgenic corn) to the average level associated with a given root rating. The net benefits from the adoption of the CRW-resistant transgenic corn technology, if the root damage rating were at the threshold value at which it would be just profitable to apply the insecticide control technology, correspond to the ***minimum*** benefits from adopting CRW-resistant transgenic corn for those who had opted to apply insecticide (because at best their root rating would have been just above the threshold); at the same time, they represent the ***maximum*** potential benefits for those who opted not to apply insecticide (because at worst their root rating could have been just below the threshold).

We calculated three important factors pertaining to the benefits from adopting the alternative CRW control methods and therefore the adoption decision: (a) economic root rating thresholds for CRW control (using both the CRW-resistant transgenic corn control strategy and the soil insecticide application strategy), (b) net benefits from CRW-resistant transgenic corn at the soil insecticide application threshold, and (c) net benefits from CRW-resistant transgenic corn relative to soil insecticide application. The economic threshold root rating is the observed root rating at which the additional control costs just equal the additional benefits of control. Analytically, the root rating threshold for treatment i, RR_i^*, is derived as follows. First, in equation (5), setting the net benefits from control strategy i relative to no control equal to zero implies:

$$CC_i = (P-H)(Y_i - Y_i^*) \quad (6)$$

where CC_i is the control cost for control strategy i (either soil-applied insecticide or CRW-resistant transgenic corn), P is the expected corn price, H is the harvest cost per bushel, and Y_i^* is the untreated yield in bushels per acre at the economic threshold for treatment i. Then we can substitute for yield, using $Y_i = \gamma RR_i$, where γ is the factor that converts root rating into yield, RR_i is the root rating associated with control strategy i, and RR_i^* is the root rating at the economic threshold for control strategy i, to obtain:

$$CC_i = (P-H)(\gamma RR_i - \gamma RR_i^*) \quad (7)$$

Rearranging terms in (7) gives:

$$RR_i^* = RR_i - \frac{CC_i}{\gamma(P-H)} \qquad (8)$$

Note that the threshold root rating increases with an increase in harvest cost or control cost and decreases with an increase in the expected corn price. The threshold decreases with an increase in the root rating associated with the control strategy because an increased root rating after implementing the control strategy implies the strategy is not as effective (i.e., it cannot achieve as much yield increase relative to untreated yield). This also implies that the threshold root rating for the insecticide control strategy will be above the threshold root rating for the CRW-resistant transgenic corn control strategy. We estimated threshold root ratings under different values for (a) the untreated yield and (b) the seed premium for CRW-resistant transgenic corn technology (one corresponding to the national average cost of conventional spray treatment).

To complete the analysis, we require an estimate of the number of acres in each region, corresponding to each combination of untreated yield and root damage rating, for each class of potential adopters of the CRW-resistant transgenic corn technology in that region. Unfortunately, these data are not available. Corn rootworm pressure within a given region can vary greatly from year to year. The variance is also very high among fields within a region for any given year. This is attributable to many factors, including cultural practices and environmental factors. As an approximation we used an average root damage rating for each region. To examine the sensitivity of the results to the regional average values for root damage ratings, as well as "moderate" estimates for root damage ratings (which apply in a "most-likely" scenario), we also evaluated the benefits assuming "high" and "low" rates of corn rootworm pressure for each region. Table 3 lists the region-specific root damage ratings under the high, moderate, and low scenarios, which are assumed to apply with probabilities of 15%, 70%, and 15%, respectively. The ranges established and probabilities assumed were primarily based on personal communication with university scientists (Dr. L. Meinke, University of Nebraska; Dr. M. Rice, Iowa State University; and Dr. K. Steffey, University of Illinois). Table 4 lists the corresponding values of untreated base yields, derived from the combinations of actual yields and root damage ratings.

In Table 5, for each region we report estimates of regional average benefits per acre from adopting CRW-resistant transgenic corn technology for both continuous and first-year corn, under our three different scenarios of low, moderate, and high CRW pressure. Total annual regional benefits, computed by multiplying the region-specific benefits per acre by the relevant number of acres in the region, are also reported in Table 5 for each scenario. The sum across regions is the total national benefit to producers, and dividing this total by the number of base acres treated gives an estimate of the overall average benefit per acre. These aggregate figures are shown in the last row of Table 5. In the moderate scenario, the total annual benefits across the 11 regions amounted to $231 million, spread across 13.8 million acres—an average of about $16.49 per acre treated.

Table 3. Actual average regional yield in 2000 and subjective distributions of regional average root damage ratings.

Region	Actual yield[a] (bu/ac)	Regional Average Root Rating[b] Low	Moderate	High
Mississippi Portal	113	1	2	3
Southern Seaboard	106	1	2	3
Fruitful Rim	175	3	4	5
Eastern Uplands	128	2	3	4
Northern Crescent	127	2	3	4
Heartland, Remaining	148	2.5	3.5	4.5
Heartland, EDV	148	2	3	4
Heartland, SBV	148	2.5	3.5	4.5
Northern Great Plains	97	2	3	4
Prairie Gateway	127	2.5	3.5	4.5
Basin and Range	128	3	4	5

[a] Yield taken for ERS budgets except for Mississippi Portal (LA, MS, TN, AR), Fruitful Rim (AZ, CA, WA, ID), and Basin and Range (UT, CO, NV, MT, WY, NM). These were calculated using USDA National Agricultural Statistics Service data and represent total production divided by acres harvested in the states indicated.

[b] The range of root damage ratings corresponding to low, moderate, and high CRW pressure was established for each region based primarily on personal communication with university scientists (Dr. L. Meinke, University of Nebraska; Dr. M. Rice, Iowa State University; and Dr. K. Steffey, University of Illinois).

Table 4. Estimates of average yield increase factor with low, moderate, and high CRW pressure and untreated base yield.

Region	Actual Yield (bu/ac)	Average Yield Increase Factor			Untreated base Yield[a] (bu/ac)
		Low CRW Pressure	Moderate CRW Pressure	High CRW Pressure	
Mississippi Portal	113	1.000	1.076	1.164	113
Southern Seaboard	106	1.000	1.076	1.164	105
Fruitful Rim	175	1.164	1.269	1.393	154
Eastern Uplands	128	1.076	1.164	1.269	126
Northern Crescent	127	1.076	1.164	1.269	124
Heartland, Remaining	148	1.119	1.214	1.328	144
Heartland, EDV (continuous)	148	1.076	1.164	1.269	145
Heartland, EDV (first-year)	148	1.076	1.164	1.269	147
Heartland, SBV (continuous)	148	1.119	1.214	1.328	134
Heartland, SBV (first-year)	148	1.119	1.214	1.328	139
Northern Great Plains	97	1.076	1.164	1.269	96
Prairie Gateway	127	1.119	1.214	1.328	119
Basin and Range	128	1.164	1.269	1.393	117

[a] Untreated base yield computed based on moderate CRW pressure.

Between the low and high scenarios, the estimates of total benefits ranged from $111 million to $406 million (or from $8 to $29 per acre). Finally, the last column in Table 5 shows the average estimate of total regional benefits, obtained by weighting the benefits under the low, moderate, and high scenarios by their assumed probabilities. Because the probability distribution is symmetric, with a high weight on the moderate scenario, the average estimates are generally similar to their moderate counterparts—a total benefit of $239 million, about $17 per acre treated.

The estimates in Table 5 are based on the regional prices of corn in 2000, which averaged $1.85 per bushel—more than 20% below the ten-year average (not adjusted for inflation). In Table 6 we compare estimates based on those prices with alternative estimates made under the assumption of a corn price equal to the ten-year average US corn price ($2.32 per bushel) for the moderate scenario. Summing across regions, the total annual benefits increased from $231 million ($16.50 per acre treated) using the 2000 regional corn price, to $319 million (just over $23 per acre treated), using the US ten-year average corn price.

Comparing across the regions, the measures of benefits vary from negligible amounts in the Mississippi Portal or Southern Seaboard up to $54 million in the Heartland Remaining region (up to $76 million in the Heartland Remaining region using the ten-year average US corn price assumption). Some of this variation is attributable to variation in benefits per acre, but variation in the number of acres treated for CRW is a much more important factor. The four regions that account for most of the benefits—the Northern Crescent, Prairie Gateway, Heartland Remaining, and Heartland SBV—also account for most of the acreage treated.

In addition to the farm-level benefits, nonfarm benefits are given by multiplying the seed premium ($12.43 per acre) by the number of acres to which it applies (13,796,901 acres)—a total benefit of $171 million. If the seed premium increases by one dollar per acre, this simply reduces the farmers' net benefits by one dollar per acre, which is exactly offset by an increase in the nonfarm benefits of one dollar per acre. As long as this hypothetical price change would not result in any changes in farmers' decisions about adopting the technology (i.e., as long as the premium was initially low enough such that the adoption decision would not be marginal), the seed premium affects only the distribution of benefits. Accordingly, even if there is an adoption response, the main impact of varying the seed premium would be for the distribution of benefits, with less-important implications for the total.

Combining the annual farmer benefits of $231 million in the moderate scenario ($319 million with the ten-year US average corn price assumption) and the annual nonfarmer benefits ($171 million), we estimate that the total annual national benefits from the adoption of CRW-resistant transgenic corn technology in the year 2000 would have been equal to $402 million ($490 million with the alternative corn price assumption).

Table 5. Farm-level benefits in 2000 from adoption under low, moderate, or high CRW pressure.

Region	Continuous or First Year Corn	Base acres treated[a]	Benefits per acre ($/acre)[b]			Total Regional Benefits ($)[c]			
			Low	Moderate	High	Low	Moderate	High	Average
Mississippi Portal	C	36		1.91	8.22		69	296	93
	F	13,079		0.82	7.13		10,725	93,253	21,495
Southern Seaboard	C	58,498		2.80	9.42		163,794	551,051	197,314
	F	104,944		4.03	10.66		422,924	1,118,703	463,852
Fruitful Rim	C	224,830	14.31	26.42	44.91	3,217,317	5,940,009	10,097,115	6,155,171
	F	220,676	13.73	25.84	44.33	3,029,881	5,702,268	9,782,567	5,913,455
Eastern Uplands	C	135,205	4.35	11.89	22.51	588,142	1,607,587	3,043,465	1,670,052
	F	63,208	3.39	10.94	21.55	214,275	691,496	1,362,132	720,508
Northern Crescent	C	1,158,988	4.74	11.87	21.89	5,493,603	13,757,188	25,370,247	14,259,609
	F	503,397	5.80	12.92	22.95	2,919,703	6,503,889	11,552,961	6,723,622
Heartland, Remaining	C	2,936,189	9.03	18.40	32.14	26,513,787	54,025,878	94,369,114	55,950,549
	F	1,829,706	8.08	17.44	31.19	14,784,024	31,910,073	57,068,530	33,114,934
Heartland, EDV	C	33,640	6.39	14.37	25.61	214,960	483,407	861,520	499,857
	F	111,954	5.32	13.42	24.81	595,595	1,502,423	2,777,579	1,557,672
Heartland, SBV	C	445,725	10.85	19.56	32.36	4,836,116	8,718,381	14,423,661	8,991,833
	F	2,507,346	9.56	18.60	31.87	23,970,228	46,636,636	79,909,117	48,227,547
Northern Great Plains	C	381,016	4.02	8.96	15.91	1,531,684	3,413,903	6,061,965	3,528,780
	F	44,431	(0.69)	4.25	11.20	(30,657)	188,832	497,627	202,228
Prairie Gateway	C	2,505,954	7.90	16.36	28.80	19,797,037	40,997,407	72,171,475	42,493,462
	F	446,796	7.40	15.87	28.30	3,306,290	7,090,653	12,644,327	7,356,049
Basin and Range	C	62,720	6.70	15.89	29.94	420,217	996,605	1,877,807	1,042,327
	F	8,563	8.05	17.25	31.30	68.932	147,712	268,022	153,941
Total		13,796,901	8.08	16.49	29.42	111,471,141	230,911,872	405,902,565	239,244,367

[a]Base acres treated from Doane's Market Research (2001).

[b]Based on data in Alston, Hyde, and Marra (2002), table 4 and tables B.1 through B.11.

[c]Average is the weighted average of "low," "moderate," and "high" using weights of 0.15, 0.70, and 0.15, respectively.

Nonpecuniary Benefits

In addition to the benefits computed above, farmers may receive other benefits that do not show up in the corn production budget. A computer-assisted telephone survey of corn farmers was conducted in late March and early April of 2002 by Doane Marketing Research, Inc., under the direction of the authors, with a view to assessing these nonpecuniary benefits. The survey sample was randomly selected from Doane's list of corn farmers.

To qualify for the survey, a respondent must have planted a minimum of 250 acres of corn in 2001 and must be the primary decision maker for purchases of insecticides and seed in their farm operation. Qualifying farmers must have also used a soil-applied insecticide for corn rootworm control on at least some of their corn acreage in 2001. The sample was weighted toward the regions with the most acreage planted to corn. Numbers of respondents by region were: Heartland Remaining (100), Northern Crescent (100), Northern Great Plains (100), Prairie Gateway (101), Heartland EDV (50), Heartland SBV (50), and all other regions combined (100). The survey respondents treated 93% of their continuous corn acres and 62% of their first-year corn acres at least once in 2001 for corn rootworm. The average price paid for all soil-applied insecticides targeted at corn rootworm on both continuous and first-year corn acres ranged from $10.56 to $11.84 per acre.

Respondents were asked a series of questions designed to elicit the value they would place on a set of nonpecuniary benefits from adopting the product, in addition to the benefits associated with increases in their average yields, including savings in handling and labor time, human safety benefits (operator and worker safety), environmental quality benefits, and more con-

Table 6. Moderate farm-level benefits in 2000 under alternative corn prices.

Region	Continuous (C) or First-year (F) Corn	Base Acres Treated[a]	Year 2000 Corn Price[b]		[illegible]	
			Per Acre Benefits ($/acre)	Regional Benefits ($)	Per Acre Benefits ($/acre)	Regional Benefits ($)
Mississippi Portal	C	36	1.91	69	3.60	130
	F	13,079	0.82	10,725	2.52	32,959
Southern Seaboard	C	58,498	2.80	163,794	3.86	225,802
	F	104,944	4.03	422,924	5.09	534,165
Fruitful Rim	C	224,830	26.42	5,940,009	36.90	8,296,227
	F	220,676	25.84	5,702,268	36.31	8,012,746
Eastern Uplands	C	135,205	11.89	1,607,587	15.72	2,125,423
	F	63,208	10.94	691,496	14.76	932,950
Northern Crescent	C	1,158,988	11.87	13,757,188	16.13	18,694,476
	F	503,397	12.92	6,503,889	17.18	8,648,360
Heartland, Remaining	C	2,936,189	18.40	54,025,878	26.02	76,399,638
	F	1,829,706	17.44	31,910,073	25.06	45,852,432
Heartland, EDV	C	33,640	4.37	483,407	19.94	670,782
	F	111,954	13.42	1,502,423	19.07	2,134,963
Heartland, SBV	C	445,725	19.56	8,718,381	26.66	11,883,029
	F	2,507,346	18.60	46,636,636	25.96	65,090,702
Northern Great Plains	C	381,016	8.96	3,413,903	13.23	5,040,842
	F	44,431	4.25	188,832	8.52	378,552
Prairie Gateway	C	2,505,954	16.36	40,997,407	21.23	53,201,403
	F	446,796	15.87	7,090,653	20.73	9,262,081
Basin and Range	C	62,720	15.89	996,621	23.85	1,495,872
	F	8,563	17.25	147,712	25.21	215,873
Total				230,911,872		319,129,407

[a]Based on data in Alston, Hyde, and Marra (2002), table A.1 and tables B.1 through B.11; base acres treated from Doane's Market Research (2001).

[b]Prices in 2000 by region were Heartland ($1.75), Northern Crescent ($1.81), Northern Great Plains ($1.66), Prairie Gateway ($1.88), Eastern Uplands ($1.87), Southern Seaboard ($1.95), and all others ($1.77).

sistent control (less yield risk). First they were asked if they agreed or disagreed with a statement that a particular benefit would be gained by adopting the product. An overwhelming percentage of respondents agreed that at least some of each nonpecuniary benefit could be gained by adoption (92% agreed it would be safer for humans and 82% agreed it would be safer for the environment than soil-applied treatment). They were then asked to place a separate value per acre on each of the benefits. In addition, they were asked to place a separate value on savings in equipment costs that might be gained by adoption and another on an increase in standability (less lodging, resulting in more harvested yield) of between two and five percent. They were then asked to give a value per acre for the *total package* of nonpecuniary benefits plus equipment cost savings and then an additional value for the nonpecuniary, equipment cost, and standability benefits. Table 7 presents the average values placed on the benefits listed above by likely adopters, unlikely adopters, and the total sample. Perhaps the most important elements of these are the value of time saved and the yield-risk reduction associated with CRW-resistant transgenic corn.

The survey results indicate the value of time saved would be $1.60 per acre for unlikely adopters, or $1.94 for likely adopters, with an overall average of $1.87 per acre. The respondents' valuation of the potential yield risk reduction from consistent insect control ranges from $1.25 per acre for unlikely adopters to $4.03 for likely adopters, with an overall average of $3.80 per acre. These are reported values when the respondents were asked to value each of the benefits separately.

Table 7. Values placed by respondents on various characteristics of the new technology relative to soil-applied insecticide applications, in dollars per acre.

[illegible]	[illegible]	[illegible]	[illegible]
1. Handling and Labor Time Savings	1.94	1.60	1.87
2. Human Safety	1.79	1.24	1.68
3. Environmental Safety	1.46	0.82	1.34
4. Consistent Control (Reduced Yield Risk)	4.03	1.25	3.80
Sum of 1 through 4	9.22	4.91	8.69
5. Equipment Cost Savings	1.57	1.00	1.46
Sum of 1 through 5	10.79	5.91	10.15
6. Better Standability (2-5% increase)	5.29	3.70	4.99
Sum of 1 through 6	16.08	9.61	15.14
Items 1 through 5 Valued as a Package	4.55	2.55	4.18
Items 1 through 6 Valued as a Package	7.24	3.86	6.61

When they were asked to value the benefits as a package, including potential equipment cost savings, the range is from $2.55 per acre for the unlikely adopters to $4.55 for the likely adopters, with an overall average of $4.18 per acre. Notice that the values placed on the total package of benefits together (both with and without standability benefits) are less than the sum of the separate values. We believe the values the respondents placed on the total packages of benefits are probably closer to their true willingness to pay for these benefits, because they were asked to value the benefits packages after they had had a chance to think further about the individual components. Applying these average benefits per acre to the 13,796,901 acres treated for corn rootworm in 2000 would imply a total additional farmer benefit of $58 million if CRW-resistant transgenic corn had been made available and was adopted on 100% of the treated acres.

Summary and Conclusion

We have examined the potential impact of the introduction of a new transgenic technology for control of corn rootworm. Under a reasonable set of assumptions and using production and price data for 2000, we found that if the technology had been available in 2000 and priced equivalent to the benchmark pesticide technology so that it would be adopted comprehensively, the benefit for farmers in the United States would have been $231 million in that year. Adding the annual nonfarmer benefits of $171 million (the benefits accruing to the technology developer and seed companies), the total benefits in the United States in 2000 would have been $402 million ($490 million, if the ten-year average corn price is used to place a value on the yield increase, instead of the actual price in 2000). The total farm and nonfarm benefit is 2.36% of the value of the 2000 corn crop.

These estimates may be understated for several reasons. First, we estimated all of the benefits using an average root-rating index. It is clear that acres with above-average root damage ratings would realize greater benefits from the technology. It is also true, as discussed earlier, that some acres below the root-rating threshold for insecticide treatment would realize a small net benefit from the new technology. Perhaps more importantly, however, the technology provides further nonpecuniary benefits to farmers, in addition to those associated with yield gains. We estimated nonpecuniary farmer benefits of $58 million if CRW-resistant transgenic corn had been made available and was adopted on 100% of the treated acres. Adding this additional $58 million to the farmer benefit from yield improvement ($231 million) increases the total farmer benefit to $289 million, and the total farmer plus nonfarmer benefit to $460 million. Table 8 summarizes the alternative estimates of the total benefits, the forms of benefits, and their distribution among farmers and others.

These estimates of pecuniary and nonpecuniary benefits to farmers and others are based on the assumption of 100% adoption—that all corn acres currently treated with conventional control methods would be switched to the new technology, instantaneously and completely. This is an extreme assumption and for that reason probably unreasonable—even under our assumption about the pricing of the CRW-resistant transgenic corn technology, which meant that it would entail lower pest-control costs and higher yields and would clearly dominate conventional pest-control technology—because some farmers have said they would not plant a crop with a

Table 8. Estimated aggregate benefits from adoption of transgenic corn rootworm technology under alternative assumptions about adoption rates and corn prices.

	Net Benefits (Million Dollars in 2000)			
	100% Adoption		30% Adoption	
Source of Benefits	Actual Corn Prices 2000	10-Year Average Corn Prices	Actual Corn Prices in 2000	10-Year Average Corn Prices
Farmer Benefits from				
a. Yield Gains	231	319	69	96
b. Nonpecuniary Benefits	58	58	17	17
Total Farmer Benefits	289	377	86	113
Total Non Farmer Benefits	171	171	51	51
Total Farmer and Nonfarmer Benefits	460	548	138	164

Note: Column totals might not add exactly because of rounding.

biotech trait under any circumstances. Our survey results indicate that this proportion of farmers may be significant, although the number of farmers in this category will probably decrease after product commercialization and adoption begins to take place. The survey results indicated that adoption might be only 30% in the first year, which would imply that the benefits in the first year would be 30% of the figure implied by 100% adoption (the relationship is linear under our assumptions unless we use a more sophisticated analysis in which the farmers identified as those who choose to adopt are those who are likely to obtain higher-than-average benefits per acre).

Table 8 shows the effects of this lower adoption rate on the pattern of benefits as well as the total. Using an adoption rate of 30%, instead of a total benefit of $460 million in the year 2000, a conservative estimate of the benefits is $138 million. This might not be the maximum annual benefit, because adoption would evolve over time with the development of information and knowledge of the technology and its impacts. Other conditioning factors on adoption and on the benefits from adoption, which have not been addressed directly, include the potential effects of refuge requirements, price discounts, or identity preservation costs, if they become a reality. It is important to remember also that the pace of technological innovation in agricultural biotechnology and other pest management systems will likely place an upper limit on the amount of time over which the maximum benefits can be realized.

Additional work could be done, both to refine the estimates of this *ex ante* study and to estimate the benefits after commercial introduction, as well as to compare the two. One of the more crucial pieces of information we need in order to improve on our *ex ante* estimates is information about the distribution of corn rootworm damage within each production region. This would allow us to calculate the benefits associated with the acres experiencing higher-than-average rootworm pressure and also to identify those acres that are not now treated but for which the technology would provide a net benefit. The relationship between root damage as measured by the root rating and ultimate yield should receive more attention as well.

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Acknowledgment

Authors are listed alphabetically; senior authorship is not assigned. The authors thank John Anderson, Jay Pershing, and John Mattingly (all of Monsanto Inc.), who gave data and advice. The authors gratefully acknowledge the financial support from the NSF Center for Integrated Pest Management and the Illinois Council on Food and Agricultural Research (C-FAR) through a Sentinel grant.